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MEMORANDUM

AERODYNAMIC CHARACTERISTICS OF THE X-15/B-52 COMBINATION

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Langley Research Center
Langley Field, Va.

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AERODYNAMIC CHARACTERISTICS OF THE X-15/B-52 COMBINATION*

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SUMMARY

High-speed wind-tunnel tests, low-speed dynamic-model drop tests, and six-degree-of-freedom motion studies were made to determine the carry loads, mutual aerodynamic interference effects, and drop characteristics of the North American X-15 through the Boeing B-52 flow field. The results indicated that the X-15 installation increased the B-52 drag at the cruise conditions by about 15 percent. Qualitative buffet measurements indicated that the X-15 installation produced no detrimental effects on the B-52 buffet characteristics in the flight range of importance. The B-52 flow field induced sizeable changes in the X-15 aerodynamic loads. These loads increased with increasing Mach number and diminished rapidly with separation distance. The magnitudes and trends of the carry loads can be calculated at low speeds when the B-52 wing induced flow angularities are used. Acceptable correlation was obtained between the results of six-degree-of-freedom motion studies and dynamic-model drop tests. Further calculations indicated that safe launches of the X-15 airplane at the design conditions of Mach number and altitude should be expected.

INTRODUCTION

Past aerial launchings of research airplanes have been made from the center-line location of the carrier airplane. In the case of the X-15/B-52 combination, practical considerations dictated an underwing carry location. This location is beneath the 18-percent-semispan station of the right wing of the Boeing B-52 airplane between the fuselage and the inboard engine nacelle. With such an asymmetrical location, questions immediately arise as to the carry and launch safety and the aerodynamic-loads problems confronting the combination.

Investigations were therefore undertaken by the Langley Research Center to determine (1) the carry loads and mutual aerodynamic interference

*Title, Unclassified.

effects from high-speed wind-tunnel tests and (2) the drop characteristics of the North American X-15 through the B-52 flow field from low-speed dynamic-model drop tests and six-degree-of-freedom calculations. For the high-speed wind-tunnel tests both models were internally instrumented with strain-gage balances, with the B-52 model having additional strain gages and a pressure gage located in the right horizontal-tail panel to obtain a qualitative measure of tail buffet as affected by the X-15 installation. The variables in these wind-tunnel tests were Mach number, angles of attack and sideslip, and control deflections of both models. In addition, tests were made with the X-15 model mounted in the presence of the B-52 model by means of a sting so that the effects of separation distance between the airplane models could be determined. The low-speed dynamic-model drop tests were made to determine qualitatively the launch safety and drop characteristics and to point out any gross problem areas that might exist. Inasmuch as the drop tests did not include the effects of Mach number, six-degree-of-freedom calculations were made on the IBM type 704 electronic data processing machine to determine the effects of Mach number. Calculations were also made to determine the effects of altitude changes at the higher Mach numbers. The static aerodynamic forces and moments of the X-15 airplane in the B-52 flow field used in these calculations were obtained from the high-speed wind-tunnel results and the dynamic rotary derivatives were estimated from the high-speed tunnel results.

The purpose of this paper is to present briefly the significant results of these investigations.

SYMBOLS

The positive directions of forces, moments, angles, and distances are defined in figure 1.

b wing span, ft

C_D' drag coefficient, $\frac{D'}{qS}$

C_L lift coefficient, $\frac{L}{qS}$

C_l rolling-moment coefficient, $\frac{M_X}{qSb}$

C_m pitching-moment coefficient, referred to $0.20\bar{c}$ location of X-15 airplane and to $0.25\bar{c}$ location of B-52 airplane, $\frac{M_Y}{qS\bar{c}}$

C_n — yawing-moment coefficient, referred to $0.20\bar{c}$ location of X-15 airplane and to $0.25\bar{c}$ location of B-52 airplane, $\frac{M_Z}{qSb}$

C_Y — side-force coefficient, $\frac{F_Y}{qS}$

$\bar{c}$ — mean aerodynamic chord, ft

D' — drag, lb

F_Y — side force, lb

h — altitude, ft

L — lift, lb

M — Mach number

M_X — rolling moment, ft-lb

M_Y — pitching moment, ft-lb

M_Z — yawing moment, ft-lb

q — dynamic pressure, lb/sq ft

R — Reynolds number

S — wing area, sq ft

t — time, sec

V — free-stream velocity, ft/sec

W — weight, lb

X,Y,Z — airplane body axes

X_w,Y_w,Z_w — tunnel wind axes

z — distance along Z-axis, measured from carry location, ft

z_w — distance along Z_w-axis, measured from carry location, ft

α_{B52} — angle of attack of B-52 water line, deg

α_{X15} — angle of attack of X-15 center line, deg

$\Delta\alpha$ — incidence angle of X-15 center line relative to B-52 water line in carry location, deg

$\Delta\alpha'$ — longitudinal incidence angle of X-15 center line relative to B-52 water line when sting mounted in the presence of the B-52 airplane, deg

β_{B52} — angle of sideslip of B-52 airplane, deg

$\Delta\beta'$ — lateral incidence angle of X-15 center line relative to B-52 water line when sting mounted in presence of B-52 airplane, deg

$\delta_a = \delta_{e_R} - \delta_{e_L}$ — differential horizontal stabilizer deflection for roll control, deg

δ_e — horizontal stabilizer deflection for pitch control, deg

δ_v — vertical-tail deflection, deg

θ — pitch angle, deg

ϕ — roll angle, deg

ψ — yaw angle, deg

Subscripts:

B52 — B-52 airplane

X15 — X-15 airplane

L — left

R — right

trim — conditions existing when $C_m = 0$

MODELS AND TESTS

A drawing of the X-15/B-52 combination is presented in figure 2. The X-15 is shown pylon mounted on the B-52 in the carry location. The detail sketch shows the outline of the cutout in the B-52 wing to accommodate the upper part of the X-15 vertical tail and the three points of suspension. The top and front views show the longitudinal and spanwise relative locations of the two airplanes. A photograph of the 1/40-scale models of the combination mounted in the Langley high-speed 7- by 10-foot tunnel is presented as figure 3. Both models were internally instrumented with six-component strain-gage balances, with the B-52 model having additional strain gages and a pressure gage located in the right horizontal-tail panel to obtain a qualitative measure of tail buffet as affected by the X-15 installation. The variables in these wind-tunnel tests were Mach number, angles of attack and sideslip, and control deflections of both models. In addition, tests were made with the X-15 model mounted in the presence of the B-52 model by means of a sting so that the effects of separation distance between the airplane models could be determined.

The 0.049-scale dynamic-model drop tests were made in the Langley 300-MPH 7- by 10-foot tunnel to determine qualitatively the launch safety and drop characteristics and to point out any gross problem areas that might exist. The constant Froude number similarity technique was utilized (ref. 1). With this procedure the X-15 models were ballasted and the free-stream velocity was reduced so that the model and full-scale translational accelerations were equal, whereby similar trajectory time histories were produced. In all of the X-15 drop tests the B-52 model was restrained. The effects of Mach number cannot, however, be determined from this simulation because of incompatible velocity criteria (refs. 2 and 3). A total of 28 drops were made in which model weight, altitude, velocity, angles of attack and sideslip, and control deflections of the X-15 model were varied.

RESULTS AND DISCUSSION

Force Tests

Effect of X-15 installation on B-52 aerodynamic characteristics.- The effects of the X-15 on the B-52 aerodynamic characteristics for longitudinal trim at a Mach number of 0.75 and a Reynolds number of 2.25×10^6 are presented in figure 4. It should be noted that the B-52 wing has a root incidence of 6° relative to the fuselage water line and, hence, the angle of attack for zero lift is approximately -6°. The addition of the X-15 installation (airplane and pylon) to the B-52 produced essentially no change in the pitching-moment characteristics and, therefore, these data are not presented. The most noteworthy effect of the X-15 on the B-52 is an increase of approximately 30 percent in minimum drag and 15 percent in drag within the cruise region. The cutout in the B-52 right wing to accommodate the upper part of the X-15 vertical tail (fig. 2) caused small right-wing-down rolling moments and small nose-right yawing moments. The addition of the X-15 installation reduced both the yawing and rolling moments (fig. 4). The maximum rolling moment indicated was estimated to require less than 0.1 percent roll control deflection for trim, and the yawing moment corresponds to less than 0.1° in sideslip angle.

Effect of X-15 installation on B-52 buffet characteristics.- In order to obtain a qualitative measure of the effects of the X-15 installation on the buffet characteristics of the B-52 horizontal tail, a flexible right stabilizer was installed on the B-52 model and instrumented with a strain gage. The stabilizer was not dynamically similar to the full-scale stabilizer. The root mean square of the tail-bending-moment fluctuations was obtained for various configurations. In the analysis of the effect of lift coefficient on the bending-moment fluctuations, the point where the root mean square of the fluctuating bending moment increased sharply was assumed to be associated with the onset of buffet. Some of the results are presented in figure 5 where C_L is plotted as a function of Mach number. The flight buffet limit is shown for the full-scale B-52 airplane. For conditions existing at a Mach number of approximately 0.4 it is possible to establish the buffet boundary, and the comparison with the full-scale airplane is excellent. The other two curves indicate the limit of the model tests, and no appreciable buffet was found for either of these conditions. The X-15/B-52 operating boundary is also presented and appears to be in a buffet-free region. Therefore, based on these model tests, it can be concluded that no buffet problem is indicated.

Effect of Mach number and angle of attack on X-15 load and moment coefficients in the carry location.- The effects of Mach number and angle of attack on the X-15 load and moment coefficients in the carry location are presented in figure 6. Inasmuch as the incidence angle between the X-15 center line and the B-52 reference water line was 2° (nose up), both scales for angle of attack are indicated. As would be surmised from past flow-interference experience (ref. 4), the effect of increasing Mach number generally caused larger magnitudes and variations with angle of attack for all aerodynamic coefficients. In order to explain subsequently the variations in rolling motions of the X-15 when dropped from the B-52, attention is called to the fact that the rolling moment usually decreases with increasing angle of attack.

Calculations of X-15 pitching-moment and rolling-moment coefficients in the carry location.- In order to explain X-15 rolling-moment and pitching-moment coefficients for the carry location, calculations were made from consideration of the B-52 flow field at incompressible speeds by the methods of references 4 and 5. Some of the calculated results are presented in figure 7 for comparison with the experimental results obtained at $M = 0.60$. The correlation is considered good. The large values of these coefficients at $\alpha_{B52} \approx -6^{\circ}$ (zero lift of the B-52) are due to the B-52 wing-thickness induced flow field. Increases in B-52 angle of attack, which caused the lift induced flow field to negate the thickness effects, resulted in decreased rolling moments. The magnitude of the pitching-moment coefficient would normally be expected to decrease with increased angle of attack because of the increased angle of downwash in the region of the tail. The negative values that exist throughout the angle-of-attack range were found to result from the large upwash angles in the region of the X-15 tail, induced by the cutout in the B-52 wing. In the calculation of the flow fields the cutout was represented by a negative vortex whose strength was evaluated, from the experimental wing lift characteristics, to be $2\frac{1}{2}$ percent of the wing vortex strength. The effects of B-52 wing camber were evaluated from reference 5 and found to be small. Since the mathematical model used to calculate the flow field of the B-52 wing was sufficient to allow calculations that are in close agreement with experiment, as seen in figure 7, the loads and moments for other vehicles for which the B-52 might be used as a carrier could probably be estimated with sufficient accuracy to determine the necessity for, and aid in the interpretation of, wind-tunnel tests.

Effect of separation distance on X-15 aerodynamic loads.- The variations of the full-scale X-15 aerodynamic loads with separation distance between the two airplanes for a Mach number of 0.75, an altitude of 38,000 feet, and an initial drop angle of 1° are presented in figure 8. In this figure the X-15 was presumed to traverse the B-52 flow field at constant angle of attack. Although large initial inputs are indicated for all components except yawing moment, these inputs diminished rapidly with small changes in distance. An interesting point to note is the initial decrease in the lift and attendant decrease in pitching moment. These decreases are presumed to be associated with the movement of the horizontal tail out of the localized region of upwash generated by the cutout in the B-52 wing.

Drop Tests

A motion-picture film supplement showing the results of the drop tests made in the Langley 300-MPH 7- by 10-foot tunnel has been prepared and is available on loan. A request card form and a description of the film will be found at the back of this paper, on the page immediately preceding the abstract and index pages.

Photographs of selected drop tests are presented as figures 9 and 10 for the empty-weight condition and as figures 11 to 13 for the full-weight condition. The conditions simulated in these selected drops are presented in table I. For photographic convenience the X-15 model was mounted under the left wing of the B-52 model. Inasmuch as the X-15 will actually be under the right wing of the B-52, it should be noted that the rolling and yawing motions induced by the B-52 flow field will be the reverse of those in figures 9 to 13.

In drop 1 (fig. 9) all X-15 control deflections were zero and the angle of attack corresponded to that for level-flight cruise (30,000 feet). The model separated satisfactorily although it gradually rolled outboard, pitched down, and yawed nose outboard. An off-design condition that corresponded to climbing flight at 22,000 feet was simulated in drop 16 (fig. 10). The model-horizontal-stabilizer deflection was -5° (to produce a nose-up pitching moment). The X-15 model pitched up sharply, rolled outboard violently, and crashed into both nacelles and the wing tip. Design drop conditions of the fully loaded airplane at 38,000 feet and a velocity corresponding to a Mach number of 0.74 were simulated in drop 9A (fig. 11). As in drop 1 the model separated satisfactorily and rolled outboard, pitched down, and yawed nose outboard. The design drop conditions were also simulated in drop 10 (fig. 12), with the X-15 model having 1° vertical-tail deflection to counter the nose outboard yawing motion that occurred in drop 9A. This control deflection resulted in the desired yawing correction and also improved the rolling motion. The model roll control (to give an inboard rolling motion) was 2° for drop 11 (fig. 13) in an attempt to correct the inherent outboard rolling motion. The desired correction was obtained with the small control deflection.

Drop tests made to determine the effect of sideslip indicated that significant rolling motions were induced but were not considered to be critical. Photographic records of the X-15 vertical-tail motions in the B-52 wing cutout indicated adequate clearance for all conditions investigated. The drop-test results indicated that safe drops should be expected for all fully loaded conditions. The same is true for the empty-weight condition if nose-up pitch control is avoided.

Drop Trajectory Calculations

Inasmuch as the dynamic-model drop tests did not include the effects of Mach number, which have been shown to have appreciable influence on the X-15 loads and moments in the carry location (fig. 6), six-degree-of-freedom calculations were made on the IBM type 704 electronic data processing machine to determine the effects of Mach number. Calculations were also made to determine the effects of altitude changes at the higher Mach numbers. The static aerodynamic forces and moments of the X-15 airplane in the B-52 flow field were obtained from the high-speed wind-tunnel results and the dynamic rotary derivatives were estimated from the high-speed tunnel results.

In order to assess the ability of the calculation technique to predict the drop motions, comparisons were made with the dynamic-model drop results. One such comparison is presented in figure 14. Although some differences exist, consideration of model asymmetries and of the parameters to be estimated in calculations such as these indicates that the correlation with the experimental results is acceptable.

The calculated X-15 drop motions for two Mach numbers are presented in figure 15. It should be noted in this figure and in figure 16 that the B-52 airplane is assumed to be in straight and level flight, and therefore, the effect of changing the primary variables of Mach number and altitude produced attendant changes in angle of attack and dynamic pressure. The initial X-15 angle of attack and B-52 trim angle of attack are listed for reference in the figure. Increasing Mach number caused only small changes in z and ψ, reduced the pitching motion θ somewhat, but reversed the rolling motion ϕ. The initially smaller roll angle existing at $M = 0.60$ is due to both the higher angle of attack and lower Mach number which result in a lower rolling-moment input. (See fig. 6.)

Presented in figure 16 are the calculated X-15 drop motions at two altitudes. The effect of increasing altitude is to reduce the intensity of the motions, particularly roll. This result is due to both the lower dynamic pressure associated with and the higher angle of attack required at the higher altitude.

CONCLUDING REMARKS

Results of high-speed wind-tunnel tests indicate that the X-15 installation increased the B-52 drag at cruise conditions by approximately 15 percent. Qualitative buffet tests indicated that the X-15 installation produced no detrimental effects to the B-52 buffet characteristics in the flight range of importance. The B-52 flow field induced sizeable changes in the X-15 aerodynamic loads. The loads increased with increased Mach number and diminished with small changes in separation distance. The magnitudes and trends of the carry loads can be calculated at low speeds by use of the B-52 wing induced flow angularities. Acceptable correlation was obtained between the results of six-degree-of-freedom motion calculations and low-speed dynamic-model drop tests. Further calculations indicated that safe drops of the X-15 airplane at the design conditions of Mach number and attitude should be expected.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., March 19, 1959.

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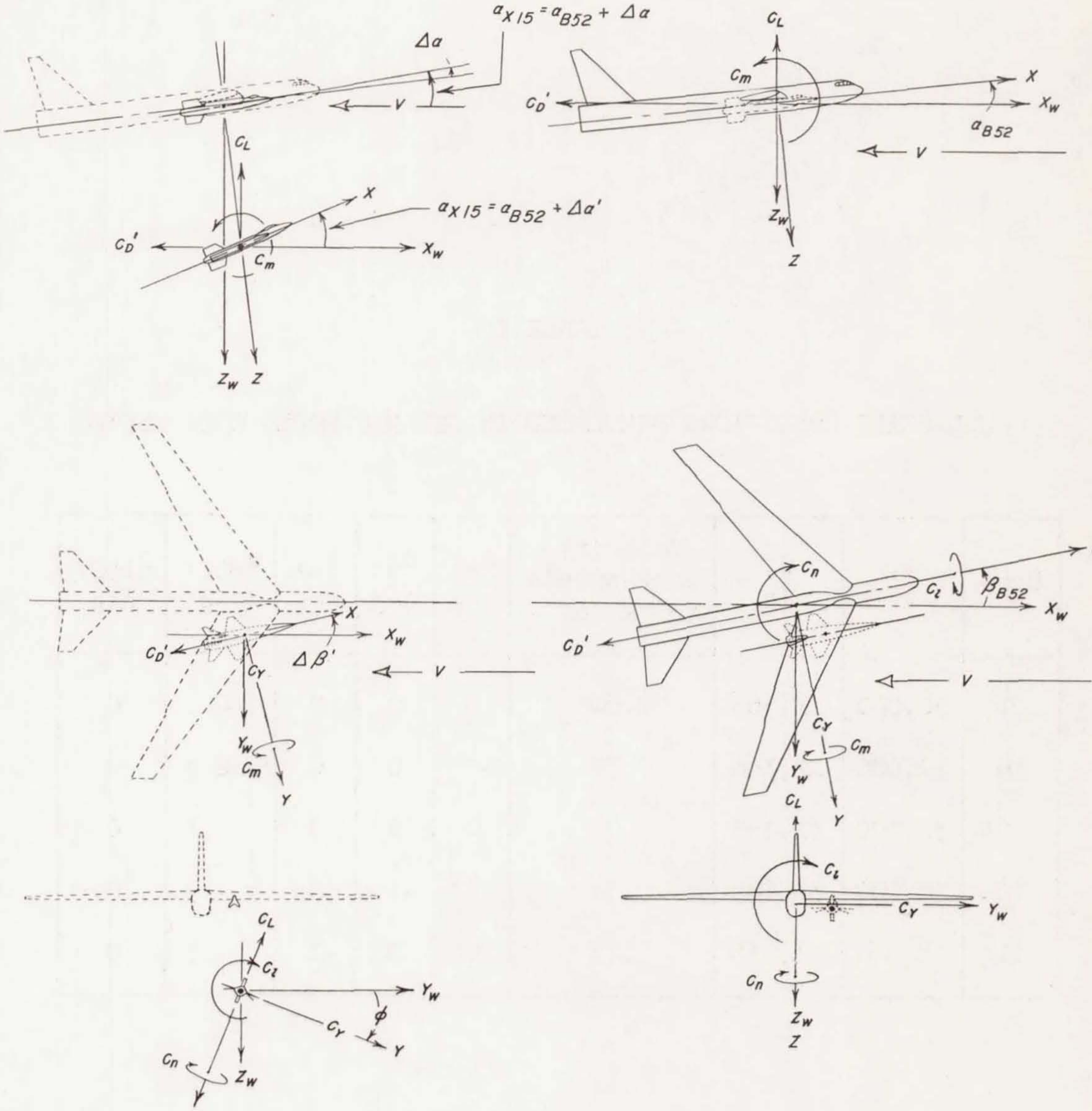
TABLE I

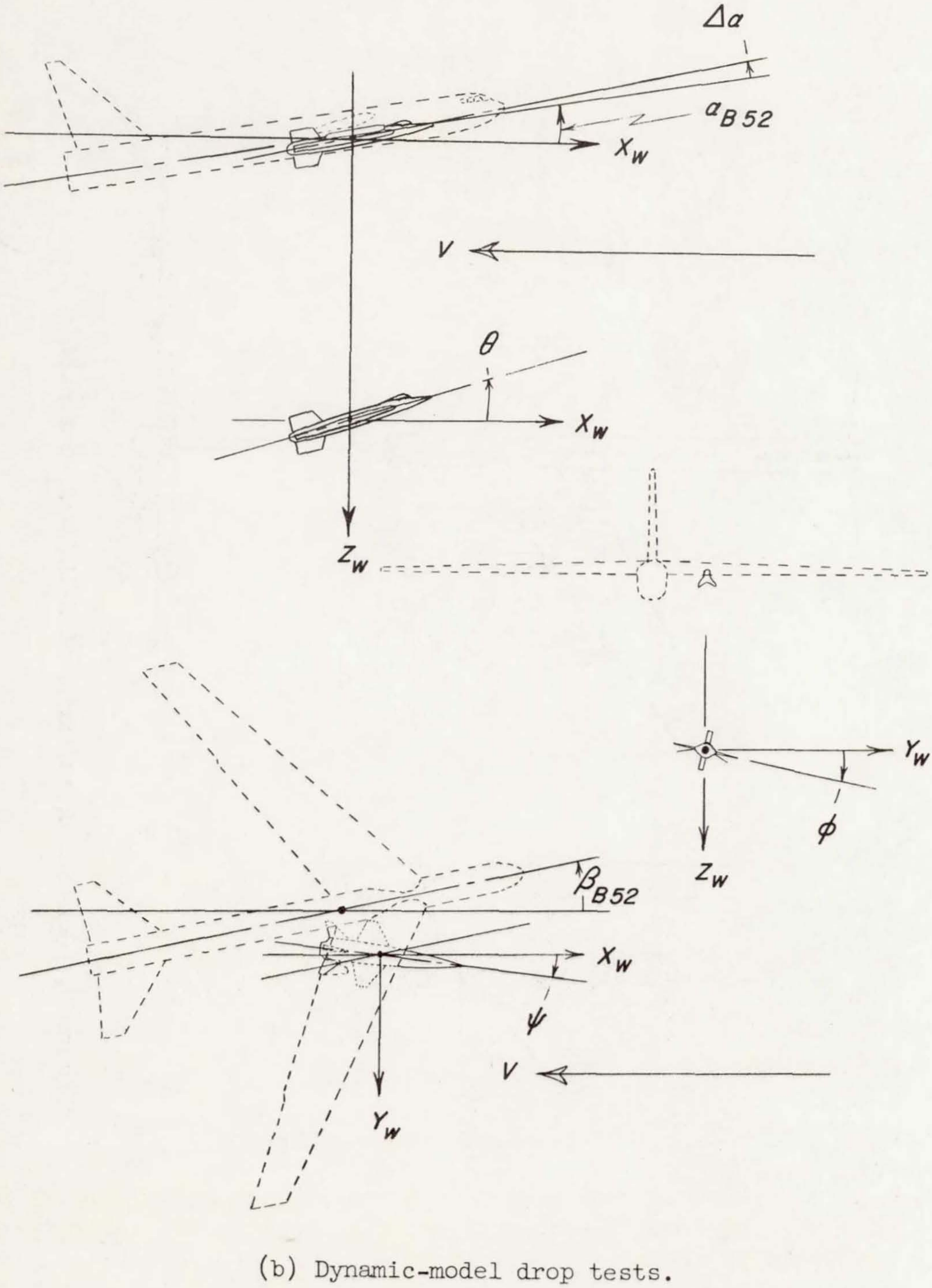
FULL-SCALE CONDITIONS SIMULATED IN DYNAMIC-MODEL DROP TESTS

Drop	h, ft	W, lb	Velocity corresponds to M of -	δ_e, deg	δ_v, deg	δ_a, deg	α_{B52}, deg	β_{B52}, deg
1	30,000	12,366	0.60	0	0	0	-0.2	0
16	22,000	12,366	.70	-5	0	0	-2.4	0
9A	38,000	31,635	.74	0	0	0	-.3	0
10	38,000	31,635	.74	0	-1	0	-.3	0
11	38,000	31,635	.74	0	0	-2	-.3	0



(a) High-speed wind-tunnel tests.

Figure 1.- System of axes used in the investigations. Positive directions of force and moment coefficients, angles, and distances are indicated by arrows.



(b) Dynamic-model drop tests.

Figure 1.- Concluded.

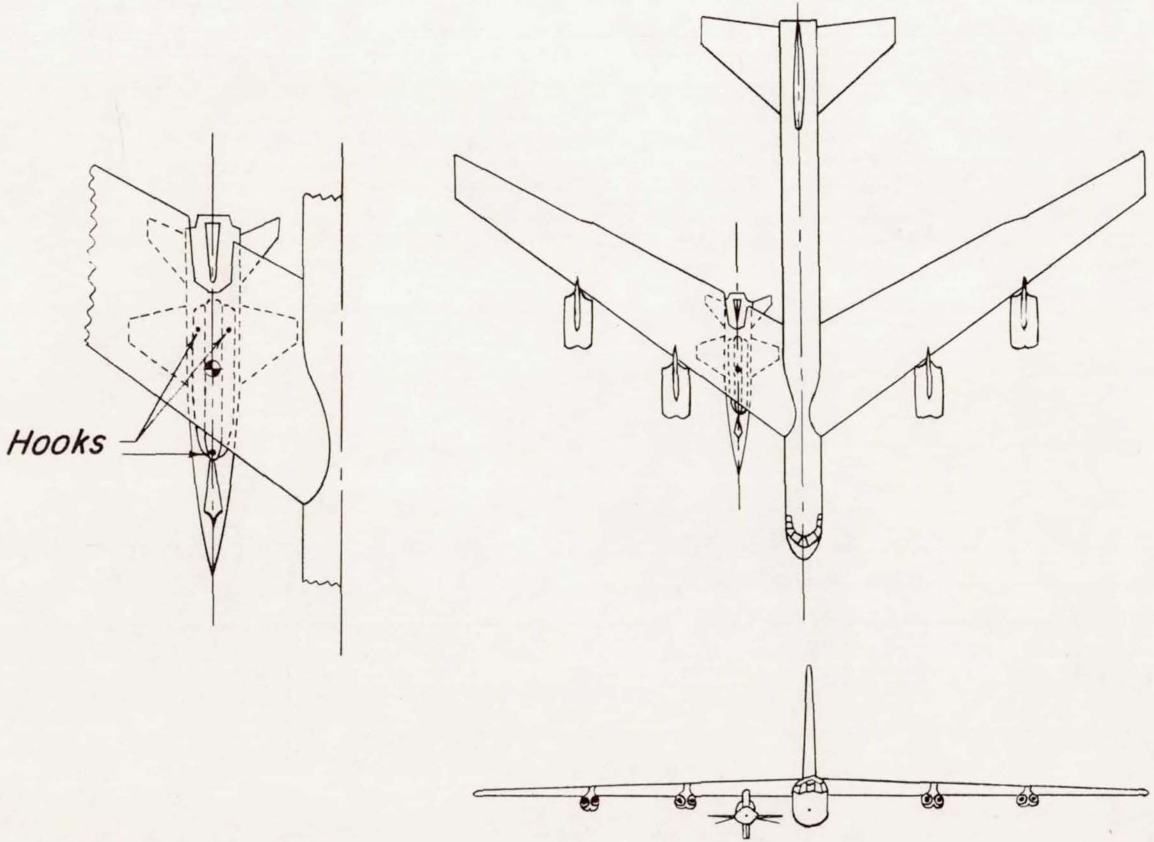


Figure 2.- General arrangement of X-15/B-52 combination.

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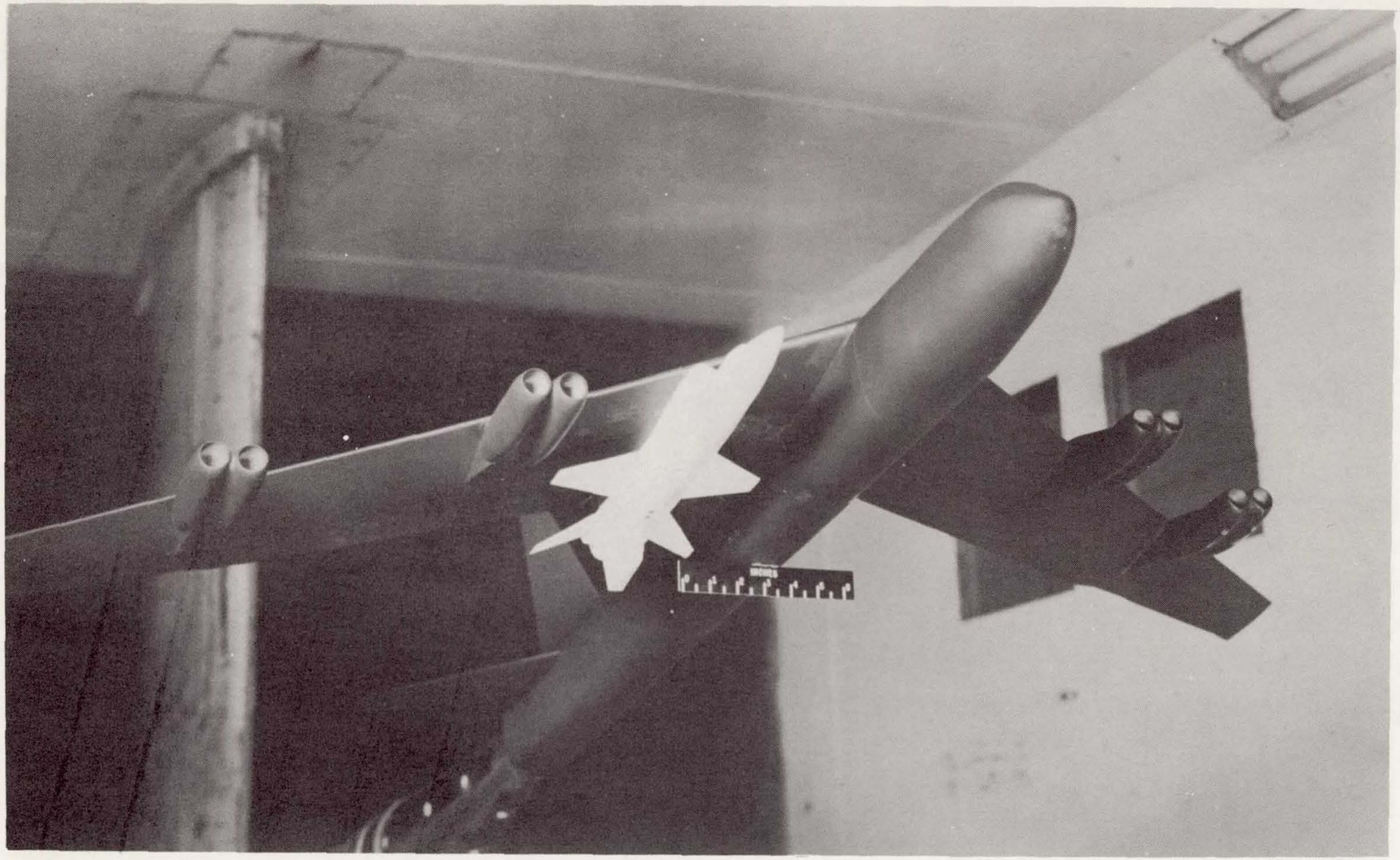

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Figure 3.- The X-15 and B-52 models in the Langley high-speed 7- by 10-foot tunnel.

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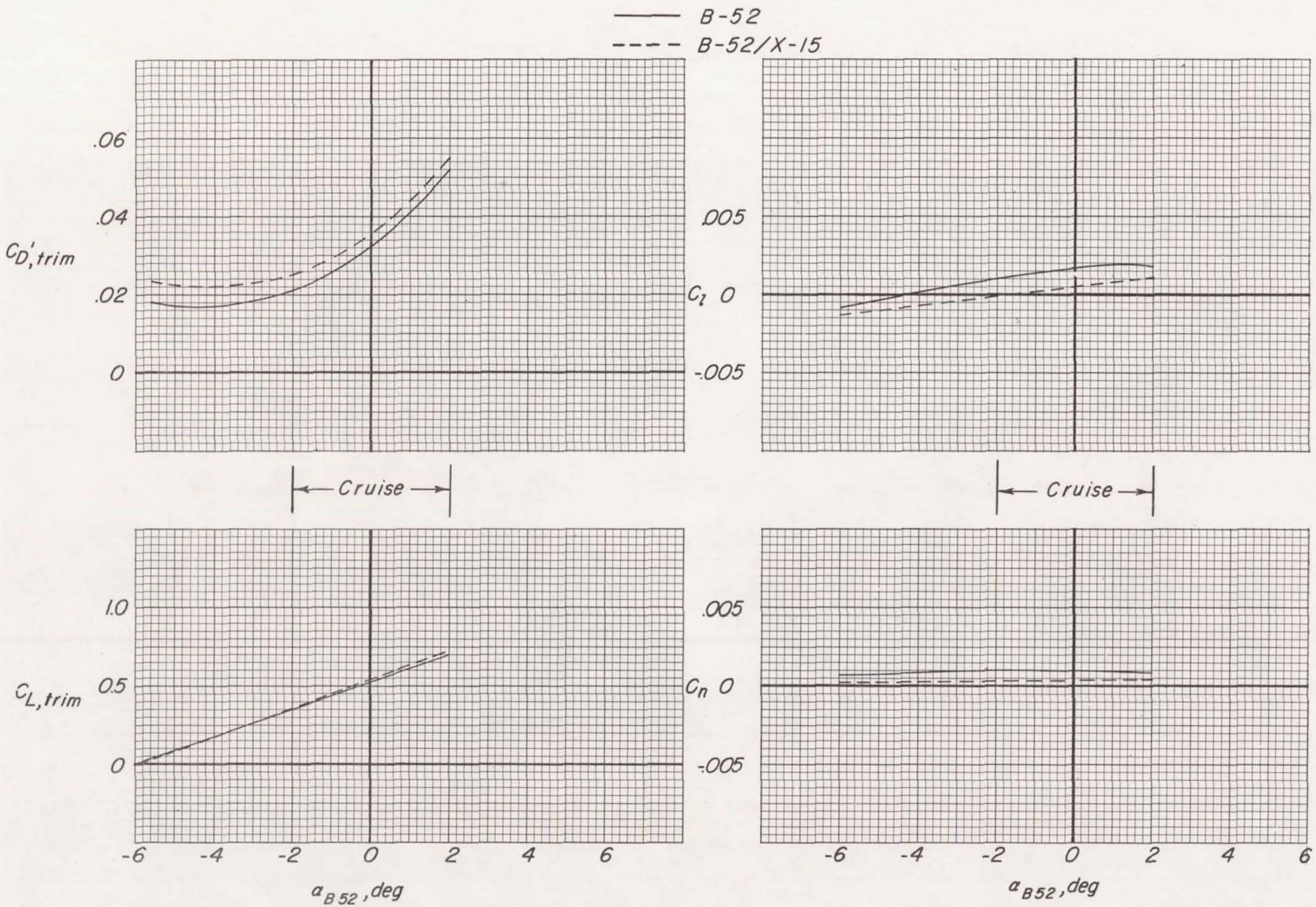

Figure 4.- Effect of X-15 on B-52 aerodynamic characteristics. $M = 0.75$; $R = 2.25 \times 10^6$.

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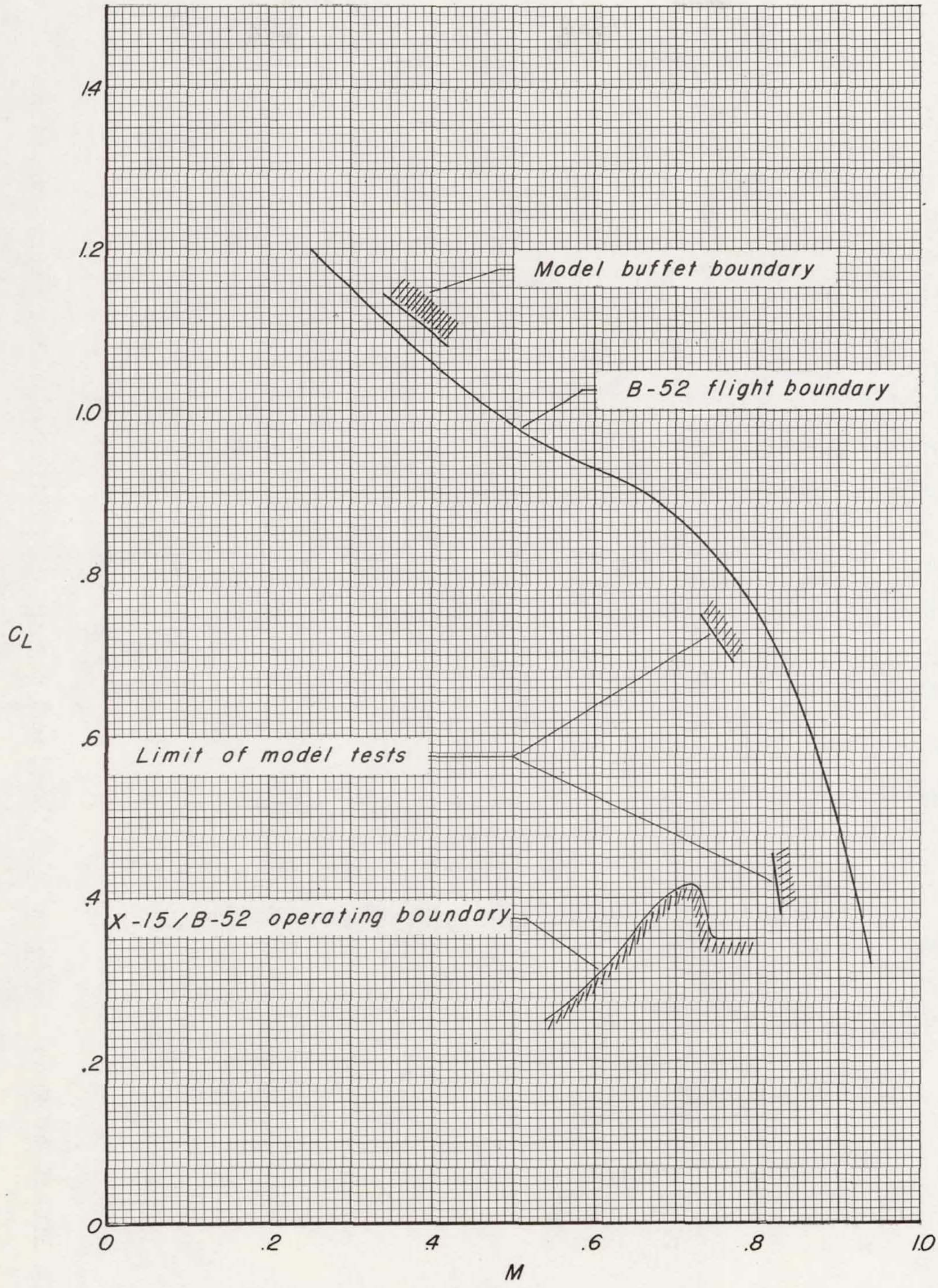

Figure 5.- Buffet boundary of X-15/B-52 combination.

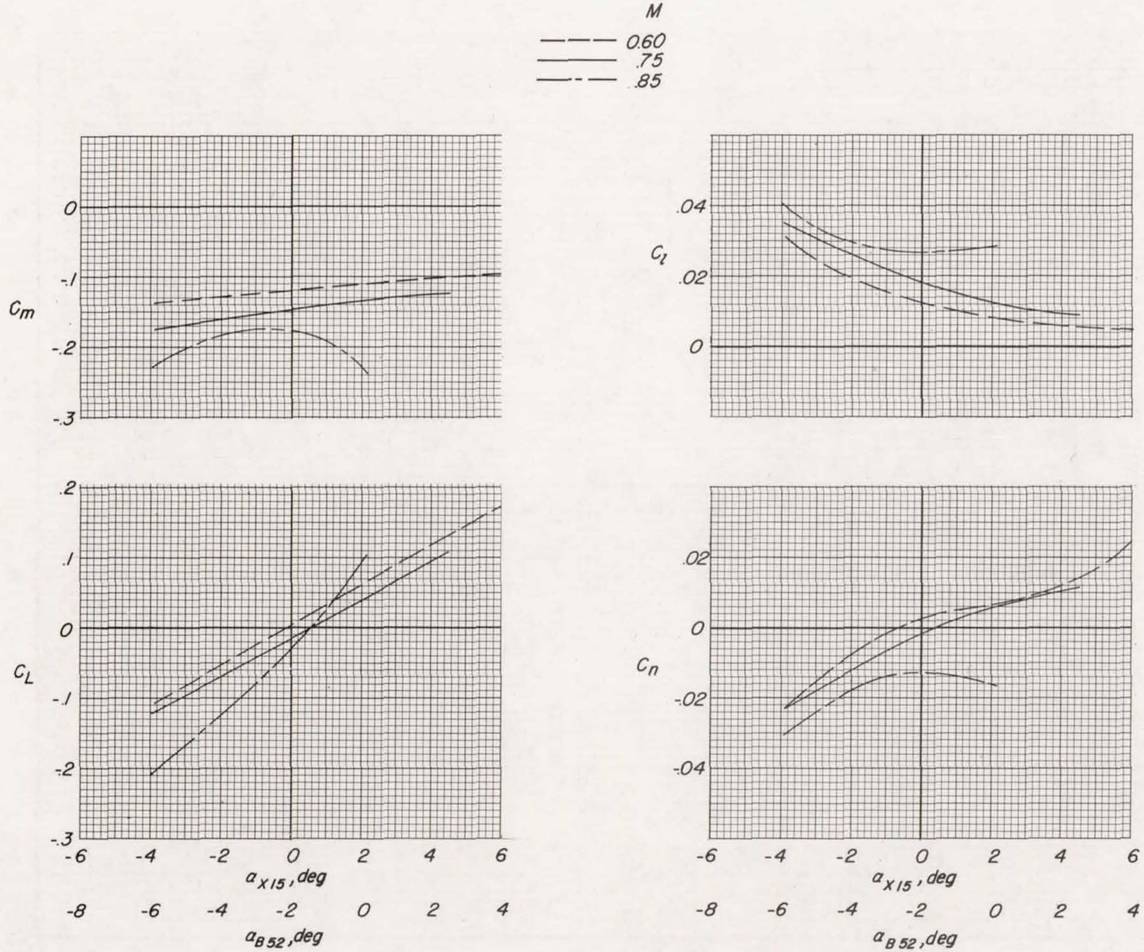

Figure 6.- Effect of Mach number on X-15 load and moment coefficients in the carry position.

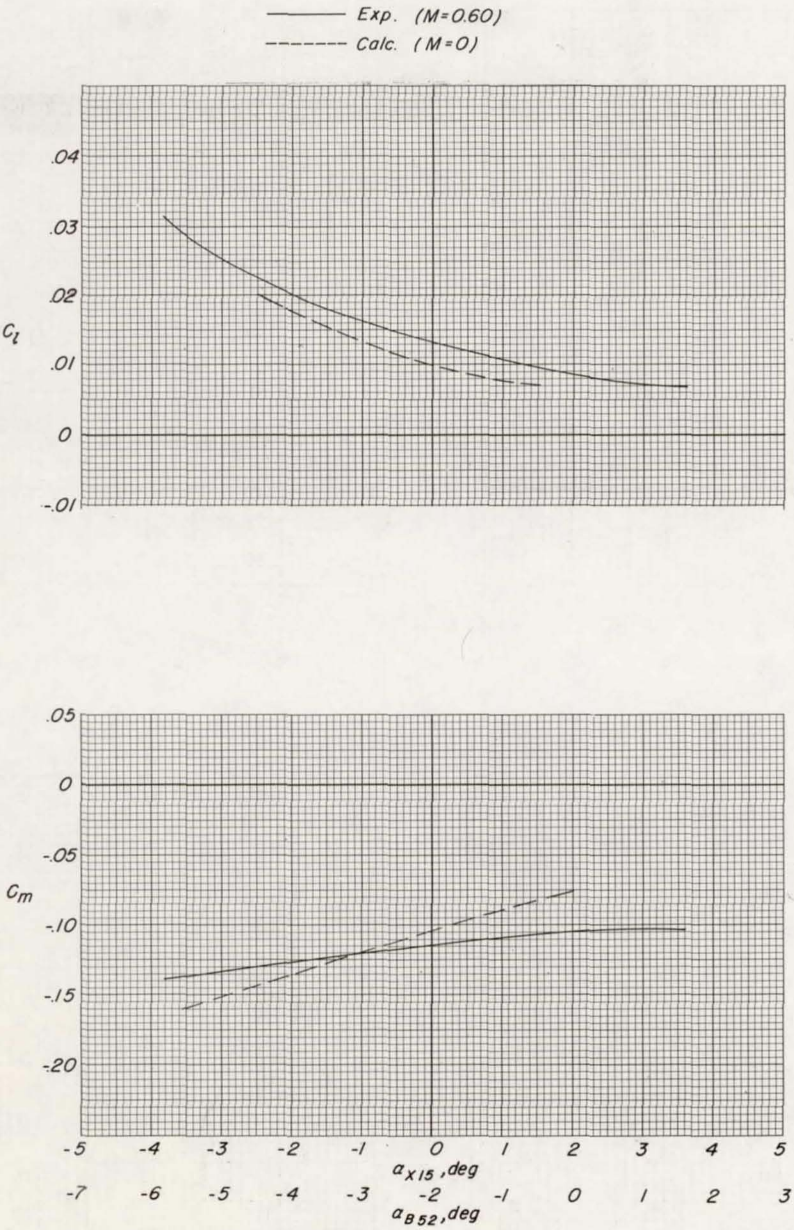

Figure 7.- Comparison of calculated and experimental rolling-moment and pitching-moment coefficients of X-15 in carry position.

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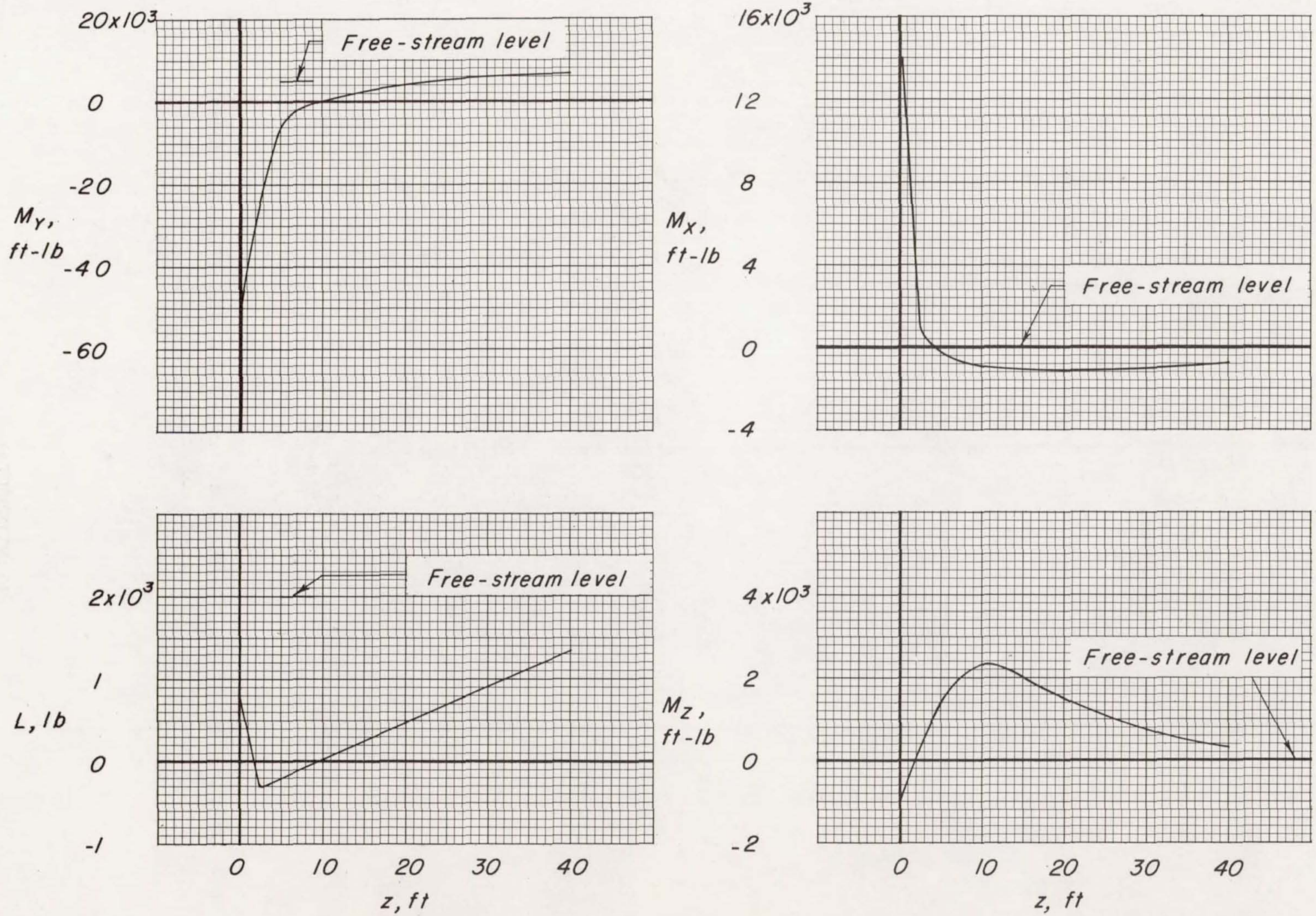

Figure 8.- Effect of separation distance on aerodynamic loads of full-scale X-15. $\alpha_{X15} = 1.0^{\circ}$; $M = 0.75$; $h = 38{,}000$ feet.

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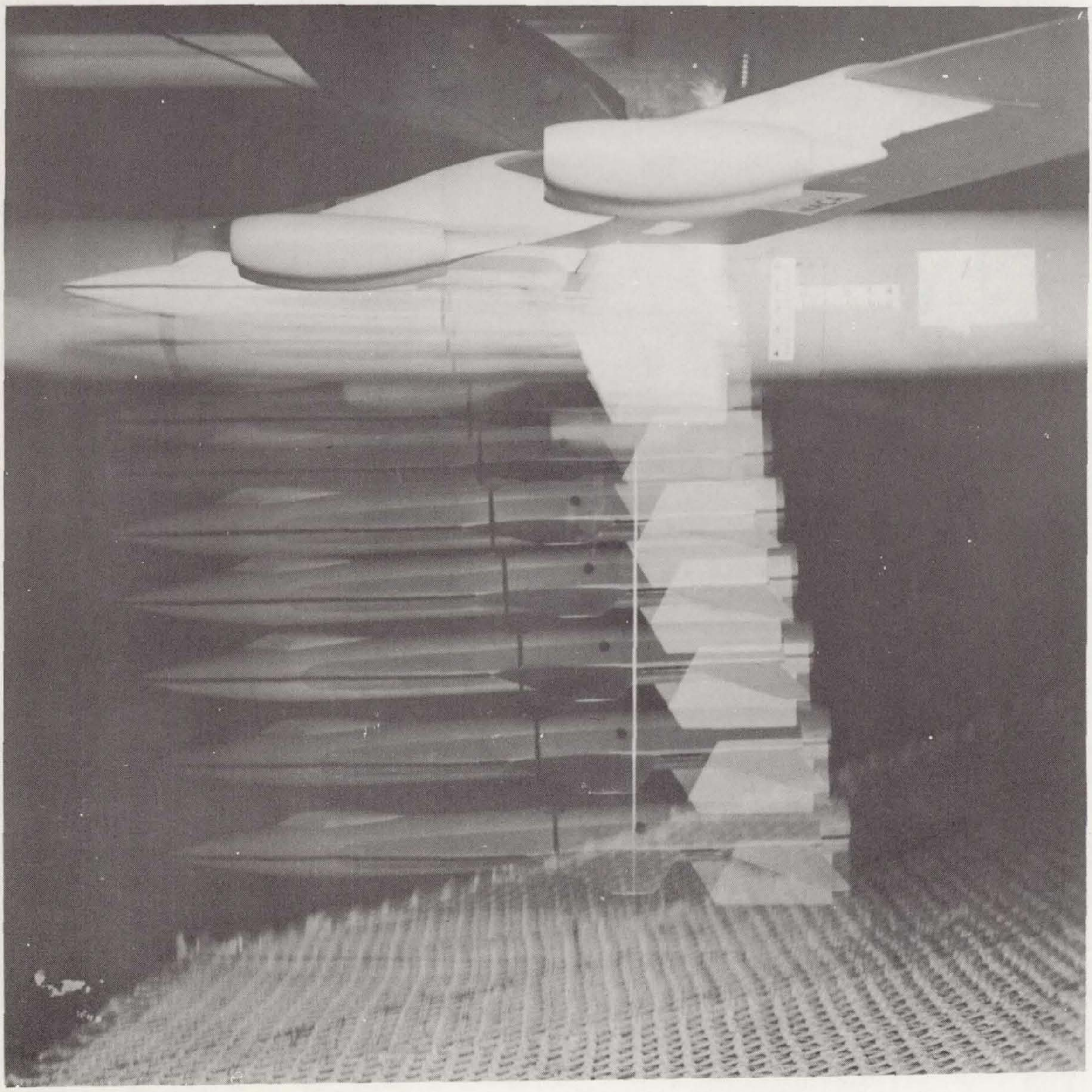

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Figure 9.- Drop 1; light model of X-15. Simulated full-scale conditions: $h = 30{,}000$ feet; velocity corresponds to $M = 0.60$; $W = 12{,}366$ pounds (empty); $\delta_e = \delta_v = \delta_a = 0^\circ$; $\alpha_{B52} = -0.2^\circ$; $\beta_{B52} = 0^\circ$.

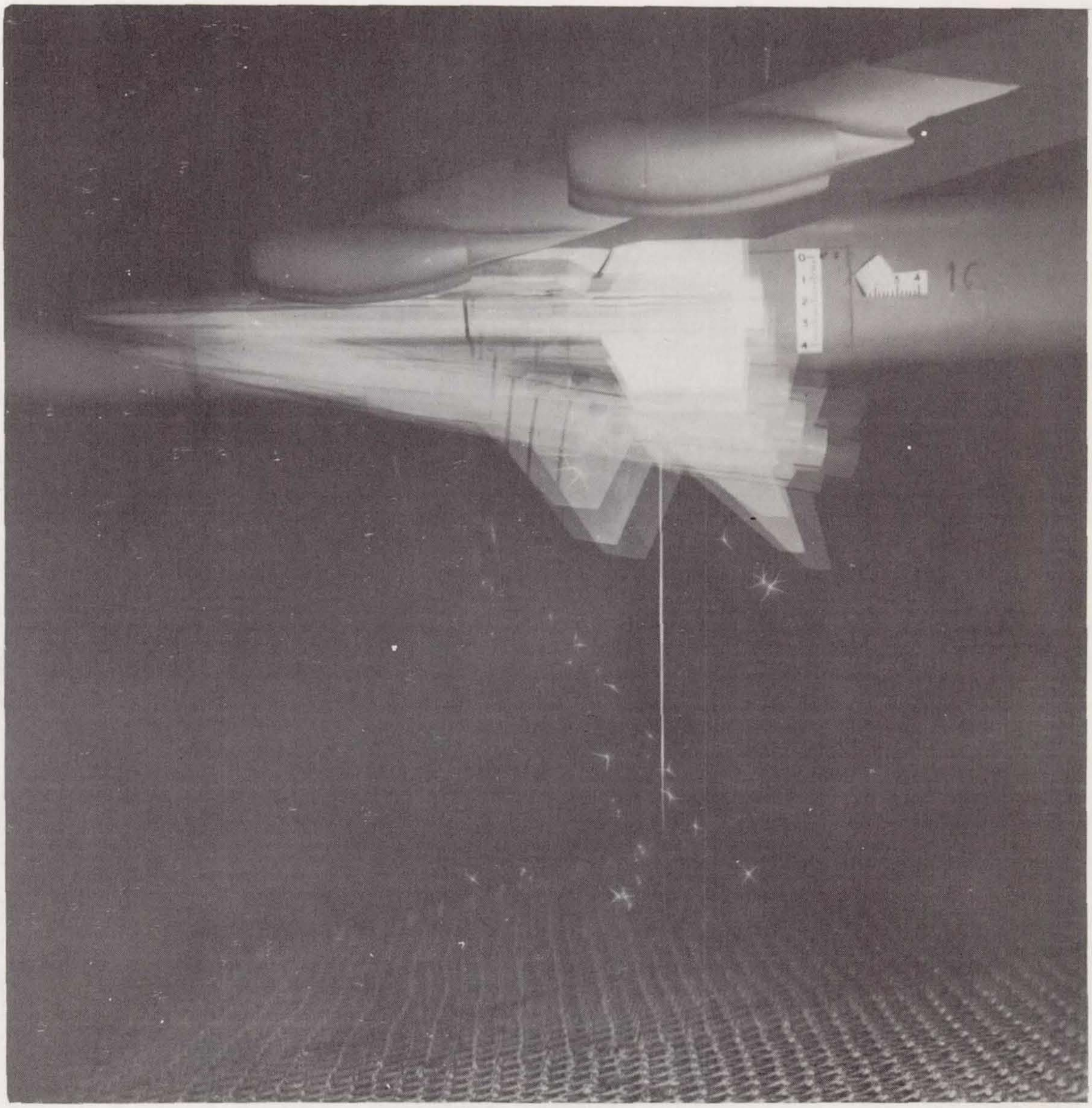

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Figure 10.- Drop 16; light model of X-15. Simulated full-scale conditions: h = 22,000 feet; velocity corresponds to M = 0.70; W = 12,366 pounds (empty); $\delta_e = -5^\circ$ (airplane nose up); $\delta_v = \delta_a = 0^\circ$; $\alpha_{B52} = -2.4^\circ$; $\beta_{B52} = 0^\circ$.

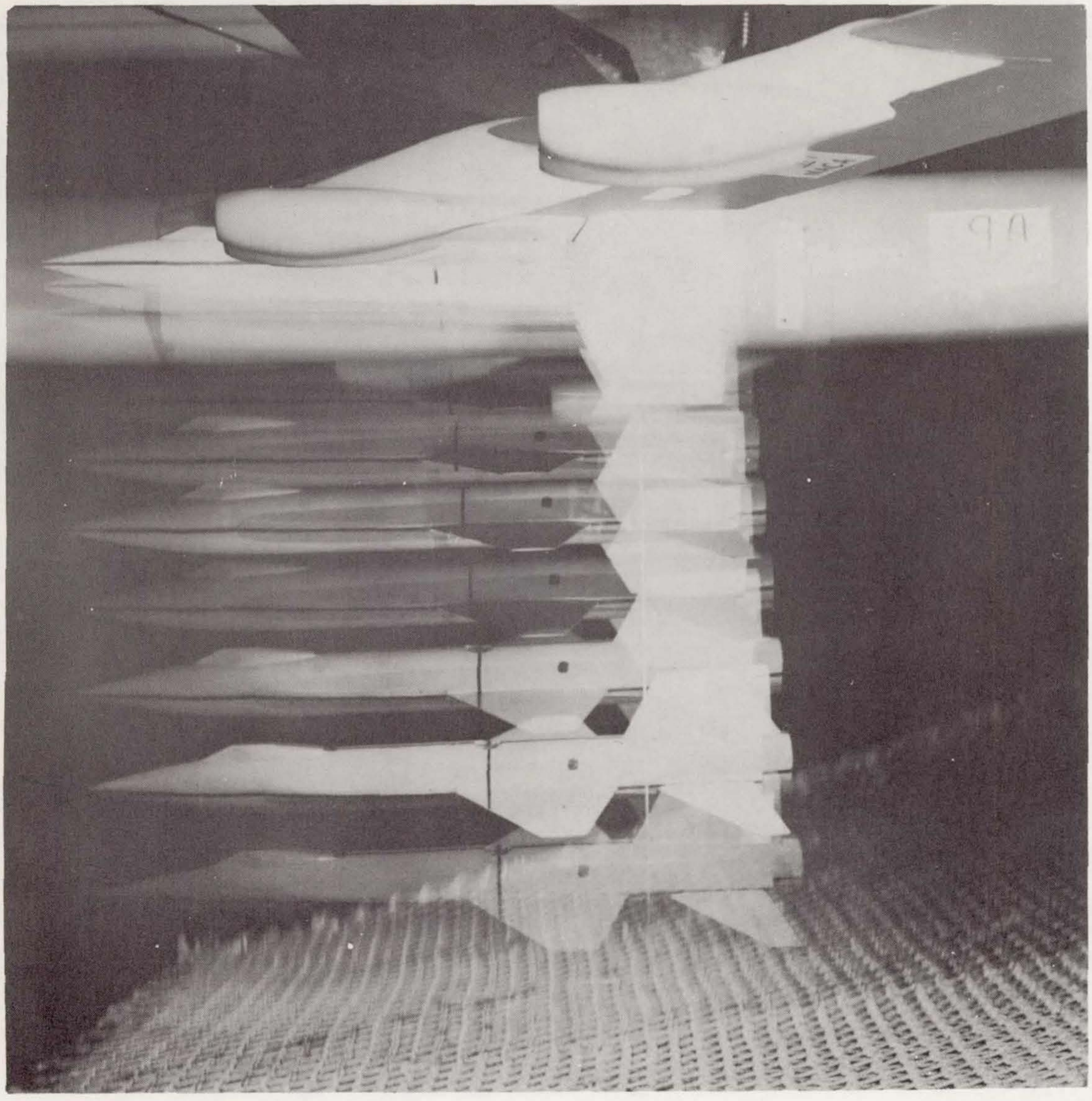

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Figure 11.- Drop 9A; heavy model of X-15. Simulated full-scale conditions: $h = 38,000$ feet; velocity corresponds to $M = 0.74$; $W = 31,635$ pounds (full); $\delta_e = \delta_v = \delta_a = 0^\circ$; $\alpha_{B52} = -0.3^\circ$; $\beta_{B52} = 0^\circ$.

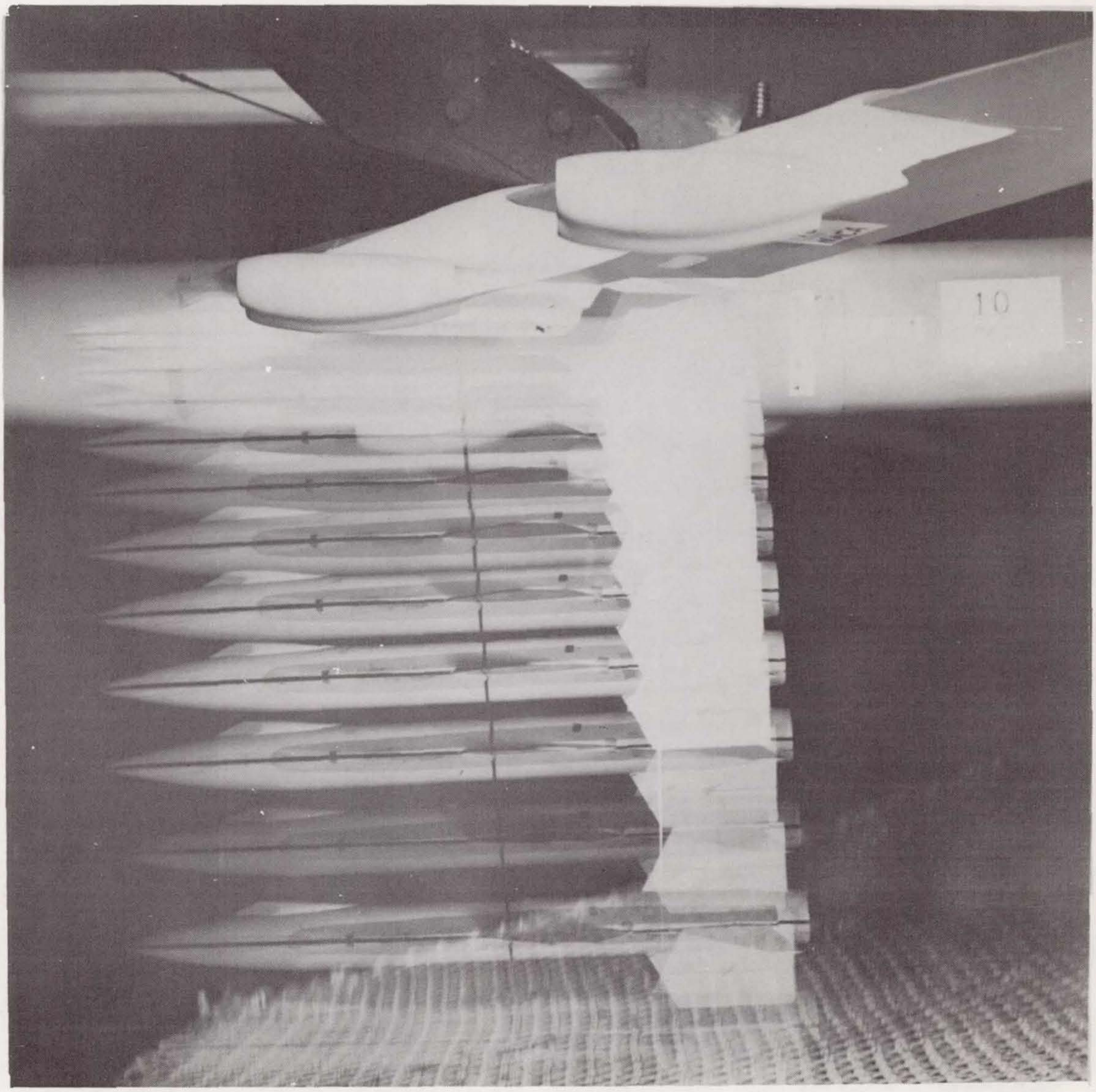

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Figure 12.- Drop 10; heavy model of X-15. Simulated full-scale conditions: $h = 38,000$ feet; velocity corresponds to $M = 0.74$; $W = 31,635$ pounds (full); $\delta_e = \delta_a = 0^\circ$; $\delta_v = -1^\circ$ (airplane nose right); $\alpha_{B52} = -0.3^\circ$; $\beta_{B52} = 0^\circ$.

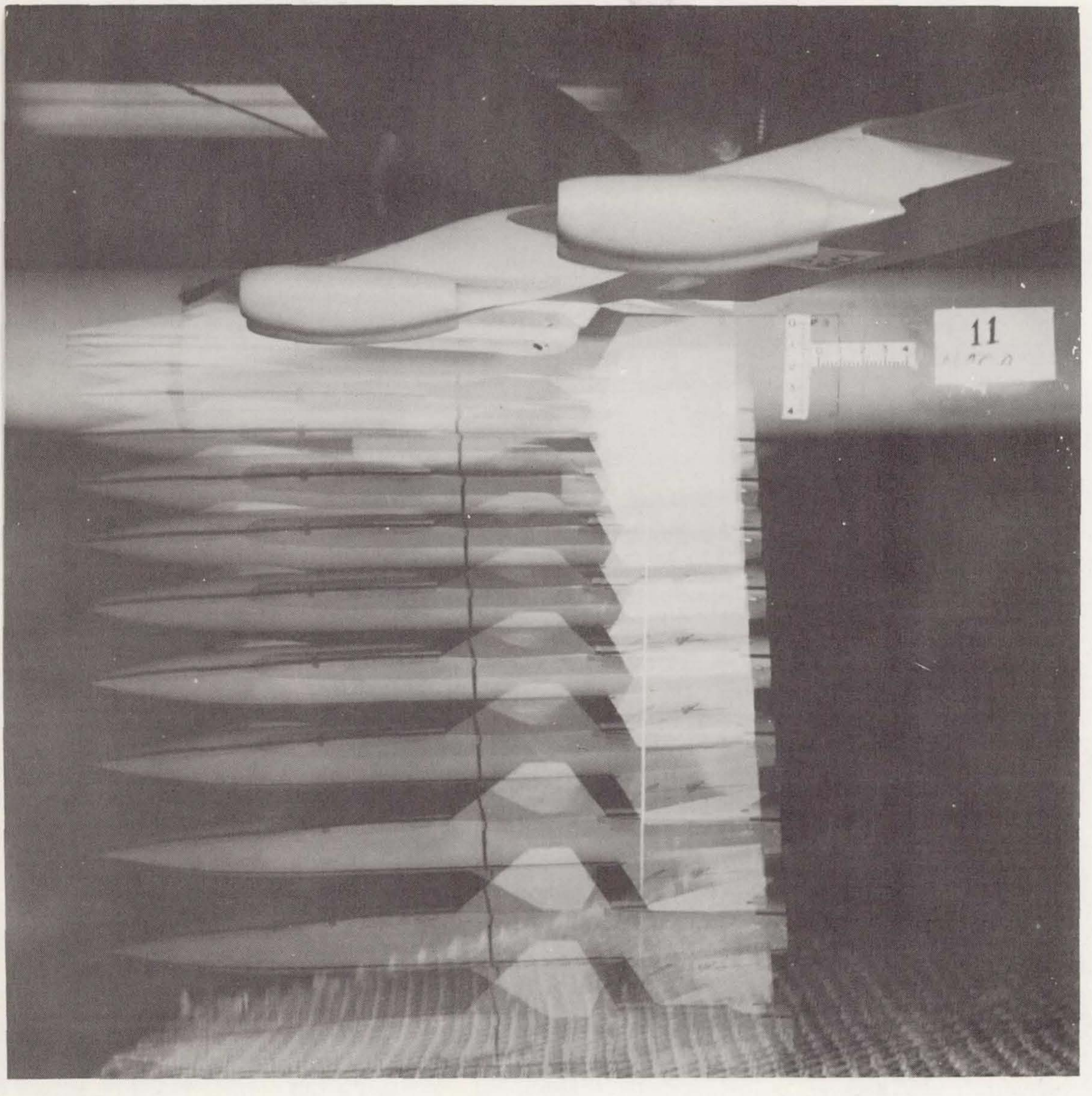

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Figure 13.- Drop 11; heavy model of X-15. Simulated full-scale conditions: $h = 38,000$ feet; velocity corresponds to $M = 0.74$; $W = 31,635$ pounds (full); $\delta_a = -2^\circ$ (airplane right wing down); $\delta_e = \delta_v = 0^\circ$; $\alpha_{B52} = -0.3^\circ$; $\beta_{B52} = 0^\circ$.

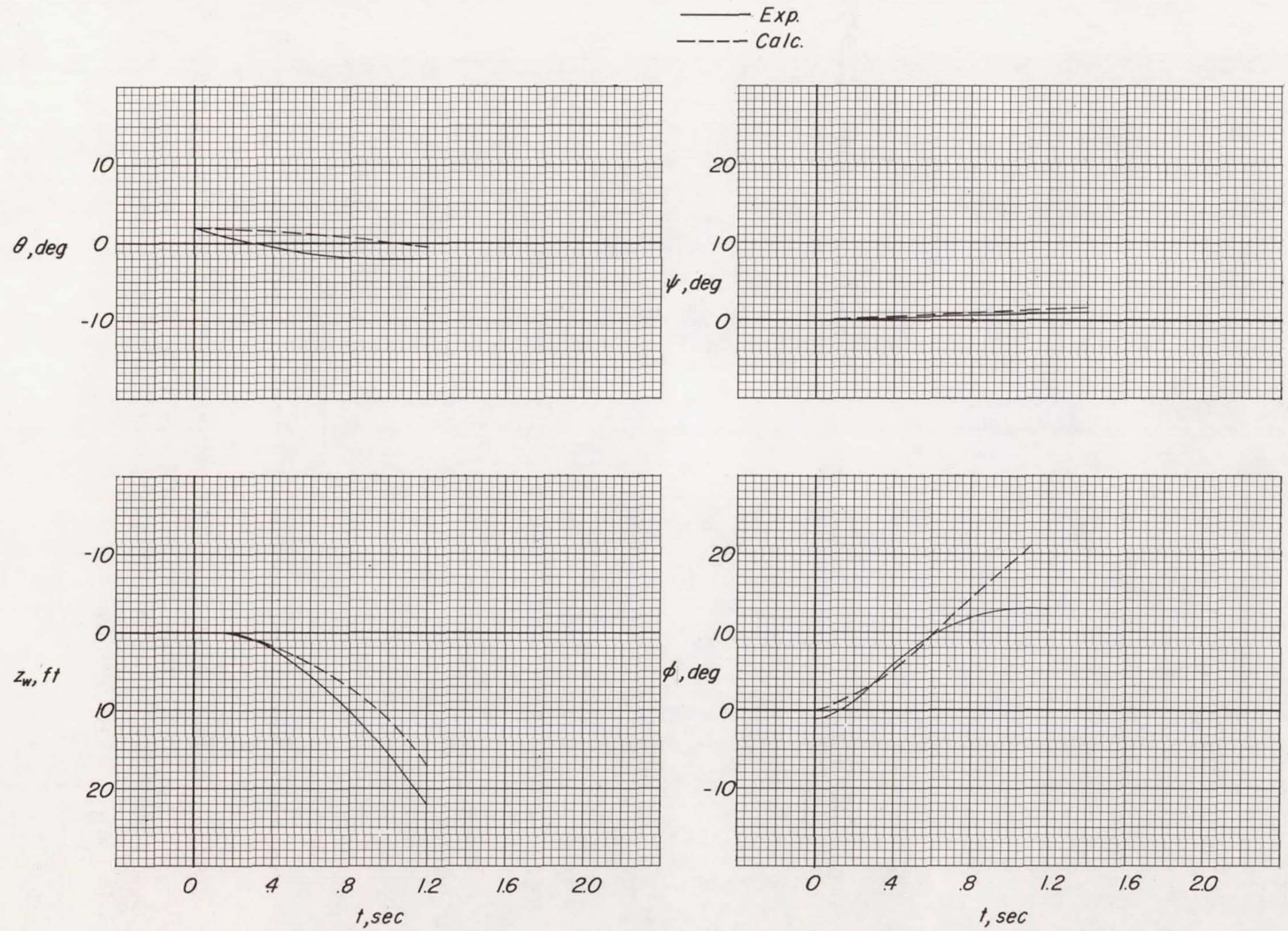

Figure 14.- Comparison of calculated and experimental X-15 drop motions. Velocity corresponds to M = 0.60; h = 30,000 feet; $\alpha_{X15} = 1.8^{\circ}$; W = 12,366 pounds (empty).

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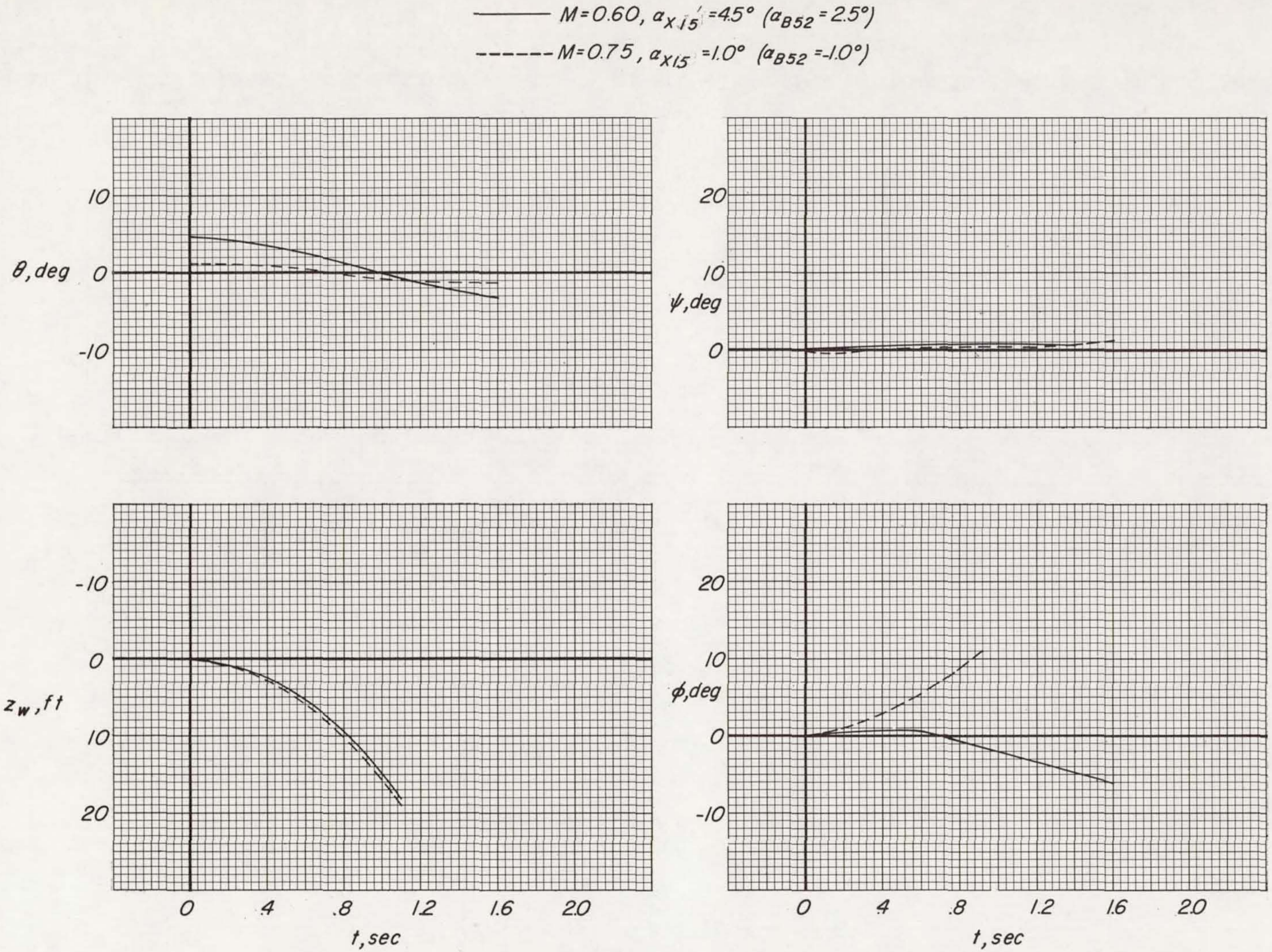

Figure 15.- Calculated X-15 drop motions at M = 0.60 and M = 0.75. h = 38,000 feet; W = 31,635 pounds (full).

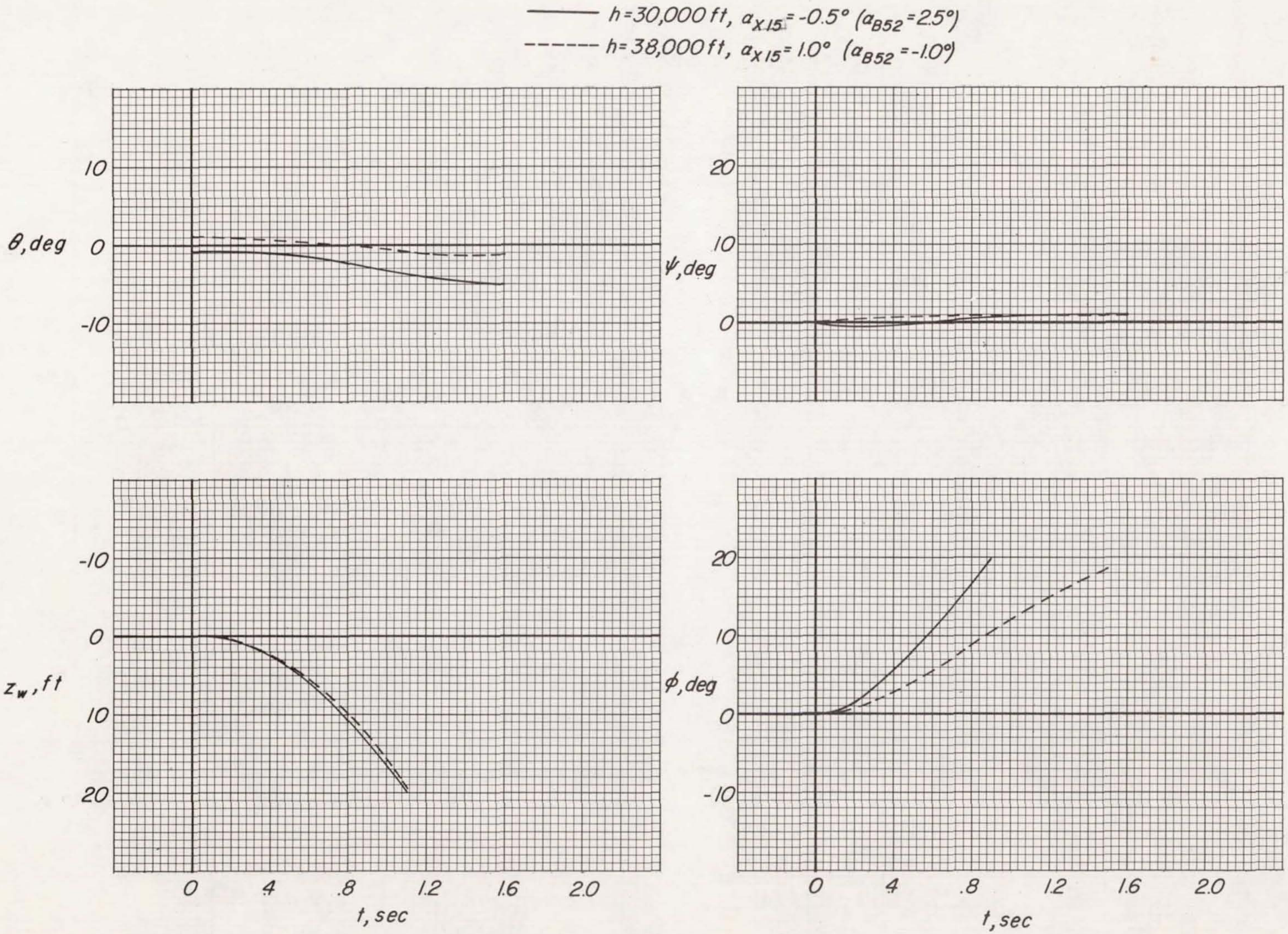

Figure 16.- Calculated drop motions of the X-15 at altitudes of 30,000 feet and 38,000 feet. M = 0.75; W = 31,635 pounds (full).

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